Improved BAQ algorithm for Tiangong-2 interferometric imaging radar data compression

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Abstract: Tiangong-2 interferometric imaging radar altimeter (InIRA), the first space-borne radar altimeter in the world, applying a new mechanism of interferometry with short baseline and small incident angle, can achieve wide swath and high accuracy sea surface height measuring. Comparing to traditional altimeter, InIRA can obtain SAR image of observation area, which means InIRA needs higher AD sampling rate. Due to the limitation of satellite on-board storage and downlink speed, in order to extend the working time of InIRA, data compression algorithm for InIRA must be studied. Block adaptive quantisation (BAQ) is an efficient and widely adopted approach for space-borne SAR raw data compression. Based on the characters of InIRA echo waveform, this study discusses compressing InIRA raw data by changing quantisation bits and size of blocks of BAQ algorithm to achieve higher compression ratio and less sea surface height error.

1 Introduction

With the development of ocean remote-sensing, traditional altimeter has been unable to meet the requirement of small orbit coverage gaps and short revisit period because of its small swath. Tiangong-2 interferometric imaging radar altimeter (InIRA) developed by National Space Science Centre (NSSC), Chinese Academy of Sciences, has wide swath (larger than 30 km) and can obtain SAR image of observation area and sea surface height. InIRA had been launched with Chinese Tiangong-2 Laboratory on 15 September 2016 and obtain a large amount of observation data. Due to its wide swath and two channels SAR imaging, the data rate of InIRA is nearly reaching 160 Mbps, which limits the working hours of InIRA and raises the requirements for data downlink and storage on-board [1].

Block adaptive quantisation (BAQ) is an efficient lossy-compression algorithm for satellite SAR data compression. BAQ algorithms partitions data to small blocks and re-quantifying data in blocks based on standard deviation of data blocks. This paper proposes an improved BAQ algorithm that can change the number of quantisation bits and size of blocks based on the characteristic of InIRA echo waveform. Comparing with traditional BAQ algorithm, it can increase compression ratio and reduce sea surface height error.

2 InIRA working principle

The sketch map of InIRA working principle is shown in Fig. 1. Equations (1)-(3) describe InIRA how to measure sea surface height [2, 3]. First, we should calculate interferometric phase \( \Delta \phi \) and range difference \( \Delta r \) of observation point \( P \) based on InIRA echo data and (1). Second, angle \( \xi \) is deduced from the triangle composed of \( B, r \) and \( r - \Delta r \), which is described by (2). Finally, the height measurement value of point \( P \) is derived by earth geometry, as shown in (3).

\[
\Delta r = \frac{\Delta \phi}{2\pi} \times \lambda \quad (1)
\]

\[
\xi = \cos\left(\frac{r^2 + B^2 - (r - \Delta r)^2}{2B \times r}\right) \quad (2)
\]

\[
h = \sqrt{r^2 + (H + R_0)^2 + 2r(H + R_0)\cos(\alpha + \xi)} - R_0 \quad (3)
\]

3 BAQ principle

Theoretical analysis proves that SAR echo data satisfies Gaussian distribution with zero mean value in both range and azimuth directions. Based on the statistics of the SAR signal, SAR raw data could be separated into many blocks. Data in each block can be re-quantised by Lloyd–Max quantiser and data size can be reduced based on the characteristics that data dynamic range in block is far less than whole data [4, 5]. The flowchart of BAQ algorithm is shown in Fig. 2 which is composed of four steps.

(i) Separate InIRA raw data into several small blocks and calculate absolute value and standard deviation in each data block.
(ii) Data quantisation via Max–Lloyd quantiser.
(iii) Transfer compressed data and standard deviation to ground station.
(iv) Decode quantisation data via Max–Lloyd quantiser and standard deviation.

4 Improved BAQ algorithm

4.1 Characteristics of InIRA echo

InIRA echo waveform is shown in Fig. 3. There are four characters of InIRA echo.

(i) The shape of InIRA echo waveform is stable when observation area is on the sea.
(ii) Based on InIRA echo searching and offset centre of gravity (OCOG) algorithm, the centre of gravity of InIRA echo waveform will change slightly at the centre of sampling window. The offset \( D \) between the centre of gravity and the centre of sampling window can be found in telemetry data.
(iii) The length of sampling window is 3000 points, which can be divided into three areas. The length of area I is nearly 600 points, and it is mainly composed of system noise. The length of area II is nearly 1800 points and the echo amplitude in area II changes
rapidly, especially at the centre of area II. The echo amplitude of area III is between area I and area II, its length is about 600 points.

(iv) InIRA works on Burst mode. Every 256 echo consists a Burst. The position of echo waveform in sampling window and the value of automatic gain control (AGC) are fixed in every Burst.

4.2 Improved BAQ algorithm for InIRA

Based on the characteristics of InIRA echo waveform, data in areas I, II, and III can be compressed using BAQ algorithm with different quantisation bits and block size to achieve better compression result. The flowchart of the new algorithm is shown in Fig. 4.

(i) Obtain offset $D$ in telemetry data and divide InIRA echo waveform into areas I, II, and III, which is listed in Table 1.
(ii) Due to different change intensity of waveform amplitude in different area, divide areas I, II, and III into 30×256 blocks, 30×32 blocks, and 30×64 blocks, respectively.
(iii) Calculate $A_Y$, which is the mean of the absolute value of echo data in every small block.

4.3 Simulation and analysis

The simulation experiment scheme is shown in Fig. 5.

(i) The result of traditional BAQ algorithm, improved BAQ algorithm, and InIRA level 0 raw data are taken as input of InIRA data processing software, respectively [6, 7].
(ii) Calculate compression ratio, coherence coefficient and sea surface height error of traditional and improved BAQ algorithm [8, 9].
(iii) Compare the impact of different BAQ algorithm on InIRA data.

We choose three observation areas to analyse coherence decrease and sea surface height error of traditional and improved BAQ algorithm. The longitude, latitude, and observation time of the three areas are listed in Table 3.

Figs. 6 and 7 show the mean coherence coefficient and sea surface height error of BAQ algorithm with different quantisation bits. Compression ratio of different BAQ quantisation bits is listed in Table 4, which is defined as (4). From Figs. 6 and 7, it can be seen that the compression rate of improved BAQ algorithm is between BAQ 8/4 and BAQ 8/5, and sea surface height error is between BAQ 8/5 and BAQ 8/6.
The ratio of sea surface height error to compression ratio $R_{SSHECR}$ for different BAQ quantisation bits is listed in Table 5, which is described as

$$R_{SSHECR} = \frac{\text{Sea Surface Height Error}}{\text{Compression Ratio}} \quad (5)$$

The effect of InIRA data compression is closely related to $R_{SSHECR}$: the less of $R_{SSHECR}$, the better of the effect. From Table 5, the improved BAQ algorithm has least $R_{SSHECR}$. It demonstrates that compared with traditional BAQ algorithm, improved BAQ algorithm can achieve higher compression ratio and less sea surface height precision loss for InIRA raw data.

5 Conclusion

In this paper, we put forward an improved BAQ algorithm for InIRA data compression with different quantisation bits and size of blocks. The experiments result shows that the new BAQ algorithm has higher compression ratio and less sea surface height error compared with BAQ 8/5. The value of $R_{SSHECR}$ also proves that the improved BAQ algorithm can obtain better result for InIRA data compression compared with traditional BAQ algorithm.

6 Acknowledgments

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7 References


Table 3 Test areas for BAQ algorithm analysis

<table>
<thead>
<tr>
<th>Test area</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Observation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Pacific Ocean</td>
<td>10°N–12°N</td>
<td>166°W–169°W</td>
<td>4 December 2016</td>
</tr>
<tr>
<td>South Pacific Ocean</td>
<td>34°S–36°S</td>
<td>74°W–79°W</td>
<td>22 September 2016</td>
</tr>
<tr>
<td>South China Sea</td>
<td>9°N–11°N</td>
<td>116°E–118°E</td>
<td>20 February 2017</td>
</tr>
</tbody>
</table>

Table 4 Compression ratio of different BAQ quantisation bits

<table>
<thead>
<tr>
<th>AD sample bits/BAQ quantisation bits</th>
<th>Compression ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAQ 8/2</td>
<td>4.0</td>
</tr>
<tr>
<td>BAQ 8/3</td>
<td>2.67</td>
</tr>
<tr>
<td>BAQ 8/4</td>
<td>2.21</td>
</tr>
<tr>
<td>BAQ 8/5</td>
<td>1.6</td>
</tr>
<tr>
<td>BAQ 8/6</td>
<td>1.33</td>
</tr>
<tr>
<td>BAQ 8/7</td>
<td>1.14</td>
</tr>
<tr>
<td>improved BAQ algorithm</td>
<td>1.70 (North Pacific Ocean)</td>
</tr>
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</table>

Table 5 $R_{SSHECR}$ for different BAQ quantisation bits in different areas

<table>
<thead>
<tr>
<th></th>
<th>North Pacific Ocean</th>
<th>South Pacific Ocean</th>
<th>South China Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAQ 8/2</td>
<td>2.76</td>
<td>2.89</td>
<td>2.75</td>
</tr>
<tr>
<td>BAQ 8/3</td>
<td>2.18</td>
<td>2.06</td>
<td>1.92</td>
</tr>
<tr>
<td>BAQ 8/4</td>
<td>1.47</td>
<td>1.33</td>
<td>1.46</td>
</tr>
<tr>
<td>BAQ 8/5</td>
<td>1.04</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>BAQ 8/6</td>
<td>0.85</td>
<td>0.59</td>
<td>0.65</td>
</tr>
<tr>
<td>BAQ 8/7</td>
<td>0.95</td>
<td>0.64</td>
<td>0.66</td>
</tr>
<tr>
<td>improved BAQ algorithm</td>
<td>0.79</td>
<td>0.54</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Fig. 5 Flowchart for analysing different BAQ algorithm influence

Fig. 6 Mean coherence coefficient over BAQ rates for different test areas

Fig. 7 Sea surface height errors over BAQ rates for different test areas

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